High-Z GaAs Development by ADVAFAB

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Content

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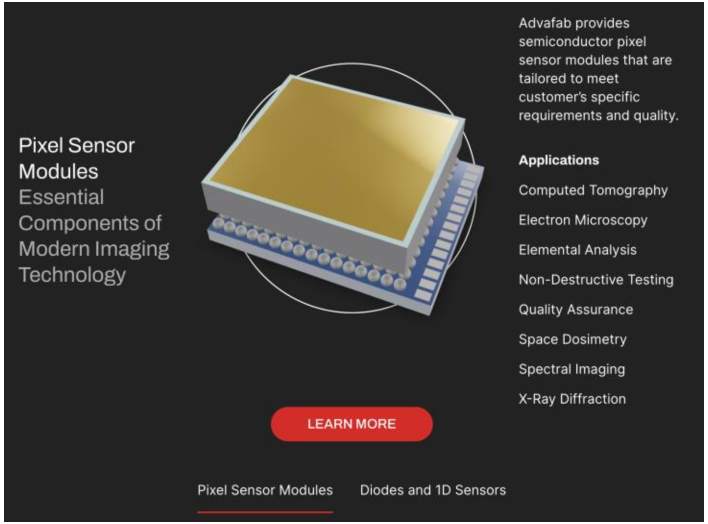
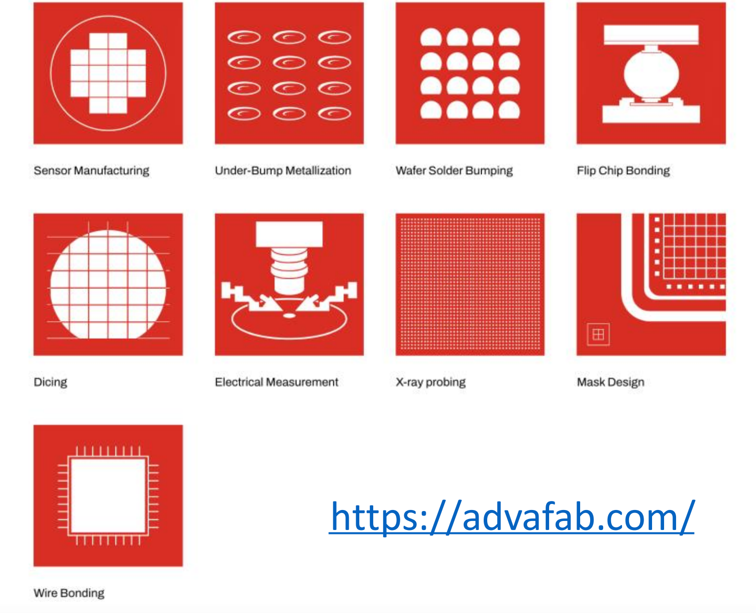
- GaAs properties and benefits
- 3” Cr compensated GaAs wafer processing
- Results with TPX1 – ADVACAM s.r.o
  - Uniformity and energy resolution
- Results with TPX3 – Amsterdam Scientific Instruments
  - Spatial resolution Si vs GaAs vs CdTe
- Results with MPX3 – X-Spectrum
  - Uniformity and edge response
- Results with TPX2 – ADVACAM s.r.o
  - Uniformity & energy resolution
  - Signal to Noise at high flux
- Contribution for benefit of EUXFEL and further work

Advacam Semiconductors is now Advafab Oy

- Advafab offers semiconductor sensor products and services
- Hybridization and sensor manufacturing productions ATLAS, CMD, LHCb, AGIPD

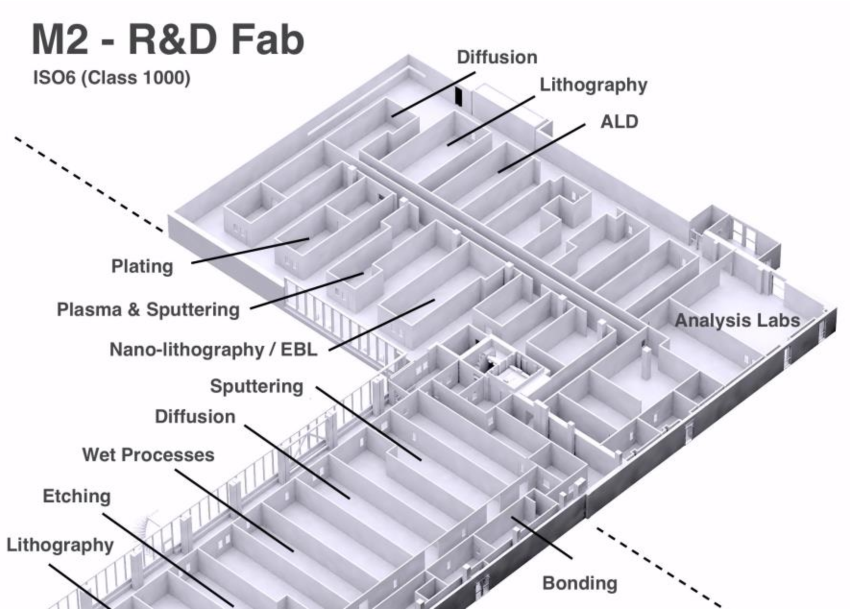




https://advafab.com/

ADVAFAB Facilities

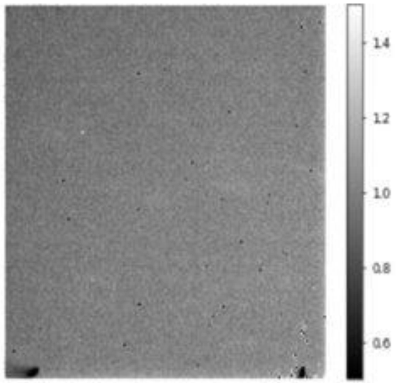
- MICRONOVA VTT's and Aalto University's R&D infrastructure with great variety of tools for semiconductor wafer processing
- Own cleanroom facility for flip chip bonding production and electrical testing



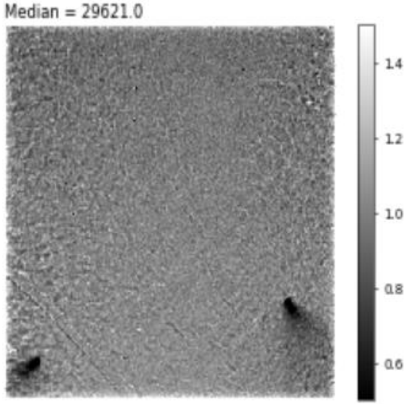
ADVAFAB's accelerated R&D

- X-ray probing offering for Medipix family readout ASICs
- Quality assurance of flip chip bonding and sensor quality => products & research
- Targets available: Fe, Cu, In & Cd
- Framework agreement with end user partners for application specific evaluations

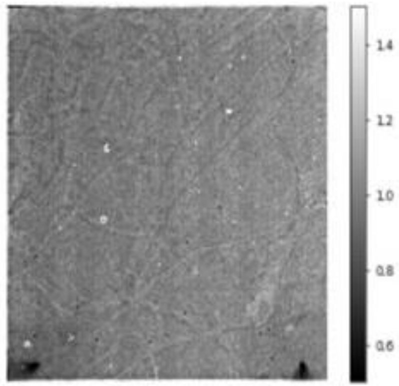
Si TPX3 module

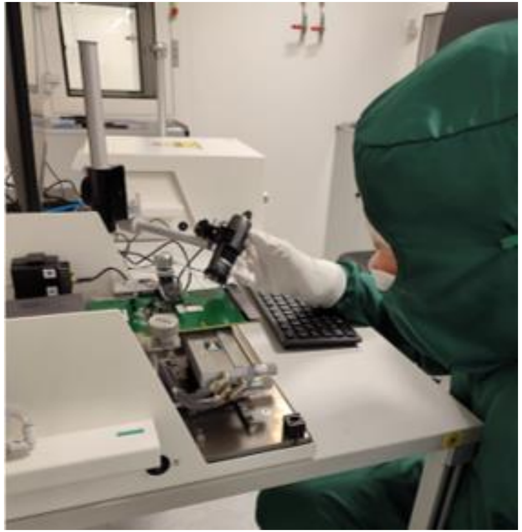


GaAs TPX1 module



CdTe MPX3 module





GaAs Properties and Benefits

GaAs properties and benefits

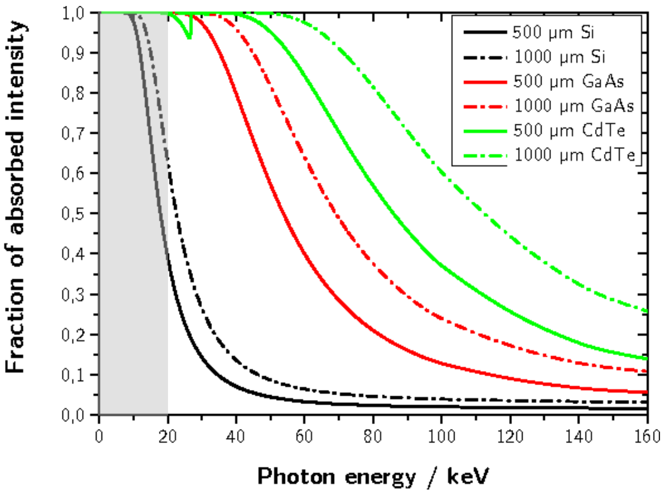
Benefits:

- Higher electron mobility (8800 GaAs vs 1400 Si) => “better” charge collection
- Higher average atomic number (32 GaAs vs 14 Si) => higher radiation absorption efficiency
- Small fluorescence probability and short distance of fluorescence photons (50%, 11-12 keV vs 85%, 26-31 keV CdTe)
- Wider bandgap (1.43 GaAs vs 1.12 Si) => superior radiation hardness
- Better stability (<0.1% GaAs vs >1% CdTe) => stable imaging properties

Material	***Silicon***	***GaAs:Cr***	***CdTe***
Average atomic weight	14	32	50
Density (g/cm3)	2.33	5.32	5.85
Band gap (eV)	1.12	1.43	1.5
Resistivity (Ohm-cm)	~1E+4	~1E+8	~1E+9
Electron mobility (cm2/Vs)	1400	8800	1100
Hole mobility (cm2/Vs)	480	400	100
$\mu\tau$ electrons	>1	~1E-4	~1E-3
$\mu\tau$ holes	>1	1-10E-6	~1E-6
Stability (10 min)	<0.01%	<0.1%	1-10%

*Several sources used

Si energy range



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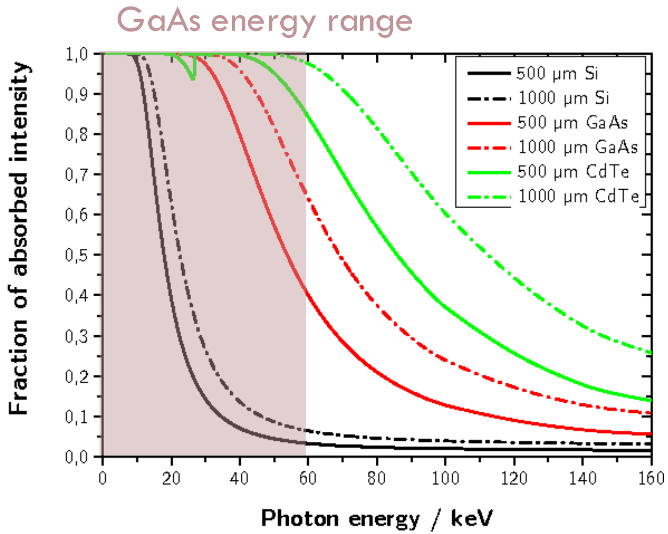

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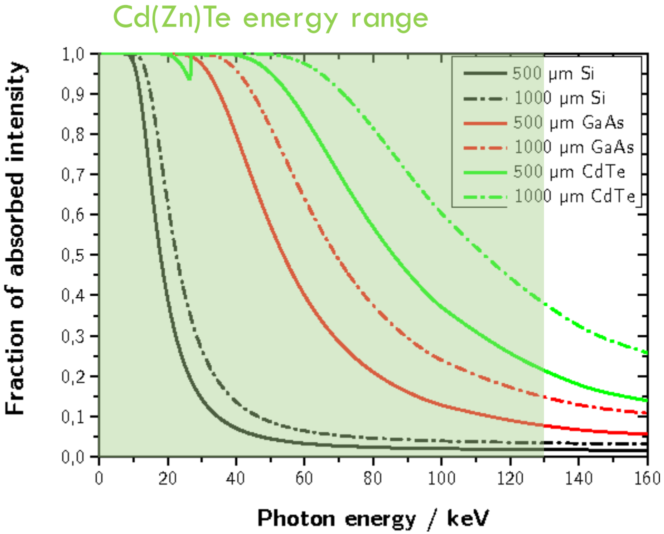


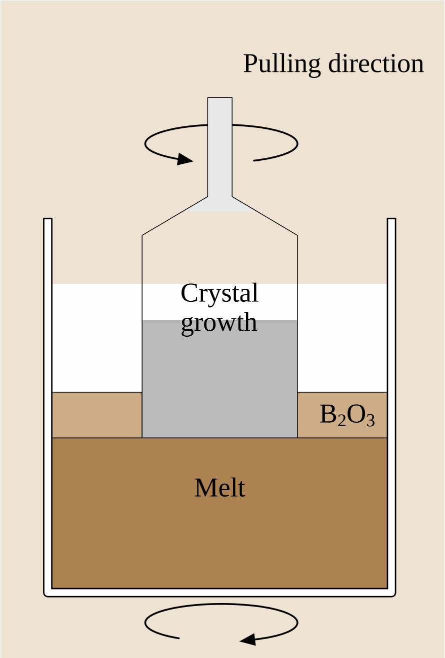
3” Cr Compensated GaAs Wafer Processing

LEC GaAs crystal growth

- In scope of our search of suitable materials for hybrid imaging sensors, we have studied post-growth compensation of n-type GaAs wafers grown by LEC method
- 3” GaAs wafers were sourced from several commercial suppliers

Wafer batch	C	D	E
Diameter, mm	76.2	76.2	76.2
Thickness, um	400+-25	750+-25	650+-25
Orientation	(100)	(100)	(100)
Mobility, $cm^2/V\cdot s$	n/a	4187	5080
EPD, cm^{-2}	9.3E4	5.6E4	1.1E5

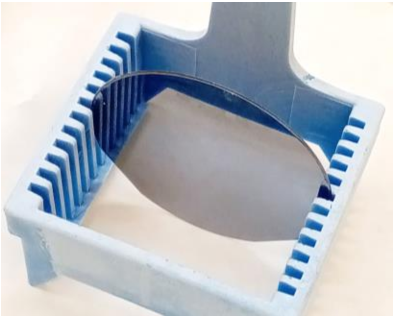
Liquid Encapsulated Czochralski (LEC)



*Materials for electronics, Part C 23

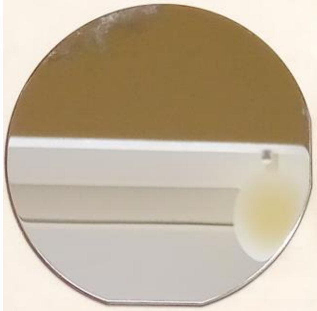
Cr compensated GaAs 3” wafer preparation

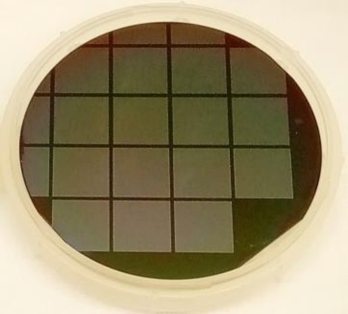
- After Cr sputtering, wafers were annealed in protective Ar ambient
- Subsequent wafer lapping and polishing was performed using Logitech PM5 tool in Tampere University
- Wafer level process steps, lithography and dicing were performed in Micronova VTT’s cleanroom facility in Espoo, Finland
- Flip chip bonding was done at Advafab facility in Helsinki

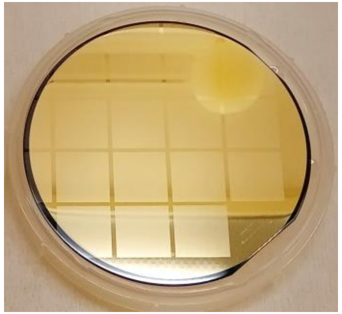


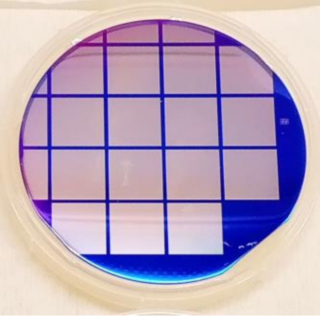
3” Cr compensated GaAs processing: Process steps

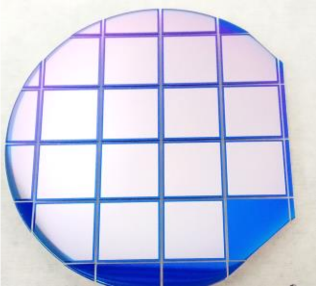
- For sensor production GaAs wafers are passing through annealing, polishing, lithography, sputtering, dicing and flip-chip bonding steps











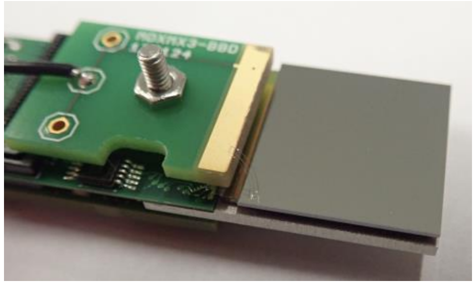
Chromium Compensated of GaAs Sensors Evaluated with TPX1

Stepan Polansky

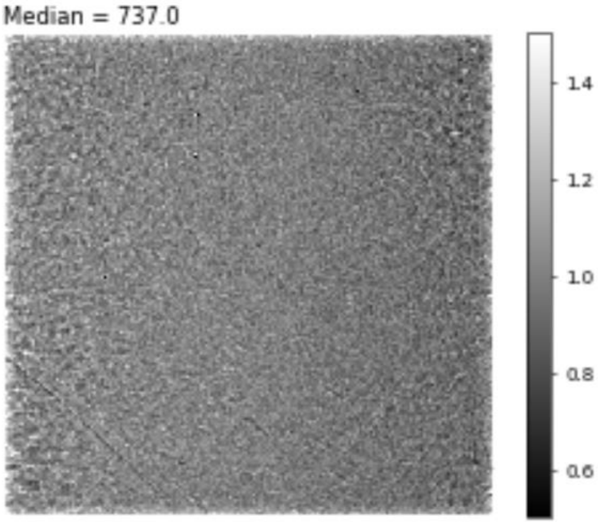
ADVACAM s.r.o

Comparison to commercially available material

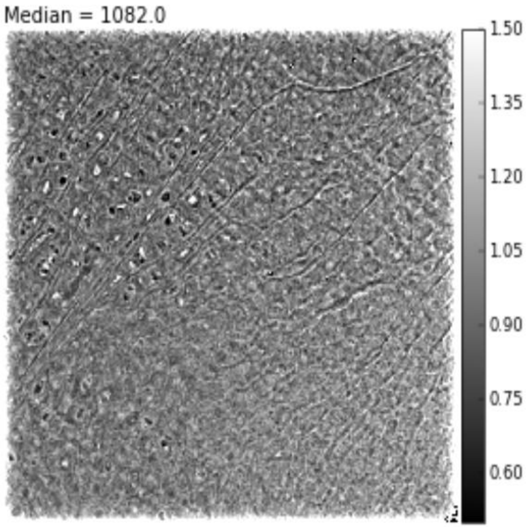
- Flat field and stability comparison
- Fluorescence of Cd target was used
- Better uniformity in Advafab GaAs
- Similar stability observed



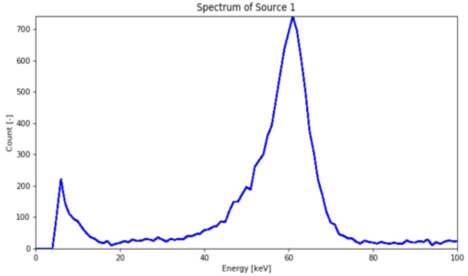
Advafab MiniPIX TPX1-GaAs 2022



Commercial AdvaPIX TPX3 GaAs 2018

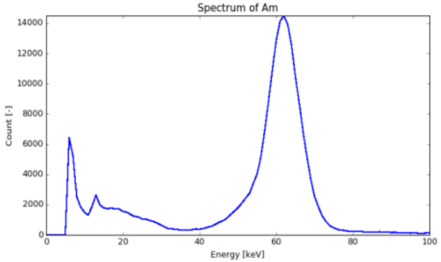


Advafab GaAs 2022



Source	Energy	Sigma
1	60.674	4.003

Commercial GaAs 2018



Source	Energy	Sigma
Am	61.554	4.140

Am TOT peak position and energy resolution

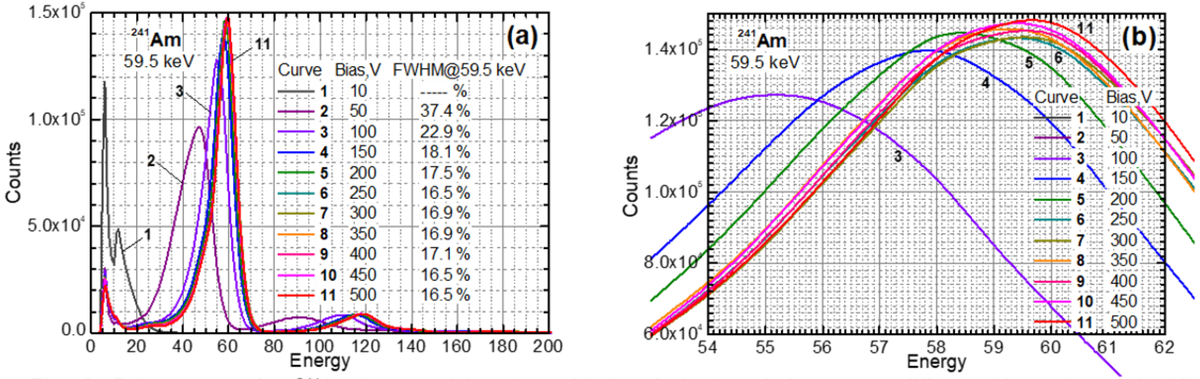


Fig. 2. Full spectra of a [241]Am isotope **(a)**, taken with the GaAs-based detector at different bias voltages *V* (V): 10 (1), 50 (2), 100 (3), 150 (4), 200 (5), 250 (6), 300 (7), 350 (8), 400 (9), 450 (10), and 500 (11); the voltage dependence of the energy position of the prominent peak (59.5 keV) **(b)** in the [241]Am isotope spectra.

V, V	E_{max}, keV
50	47
100	55.15
150	57.85
200	58.4
250	59.45
300	59.55
350	59.25
400	59.55
450	59.4
500	59.7

Table 1. Energies at which the prominent peak of [241]Am isotope spectra was observed at different voltages, applied to the GaAs-based detector.

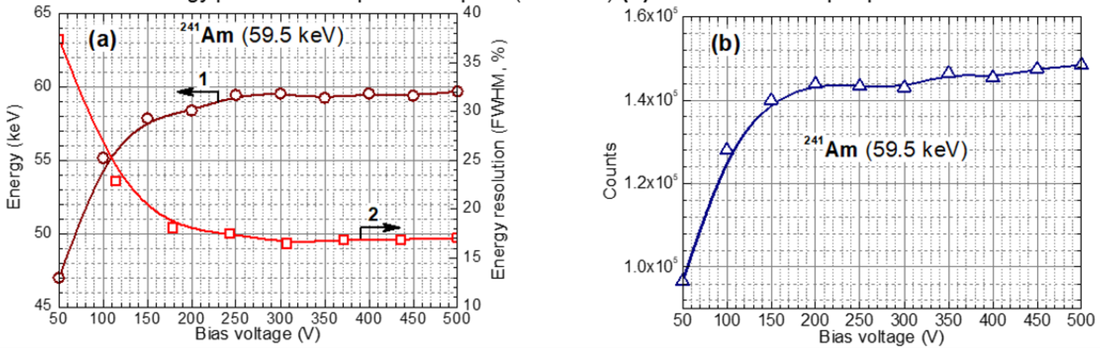


Fig. 3. Voltage dependences of the energy position (curve **1**) of the prominent peak (59.5 keV) in the [241]Am isotope spectra, taken with the GaAs-based detector, energy resolution (curve **2**) of this peak **(a)**, and detection efficiency (number of counts) of the detector **(b)**.

Chromium Compensated of GaAs Sensors Evaluated with TPX3

Erik Maddox, Erik Hogenbirk

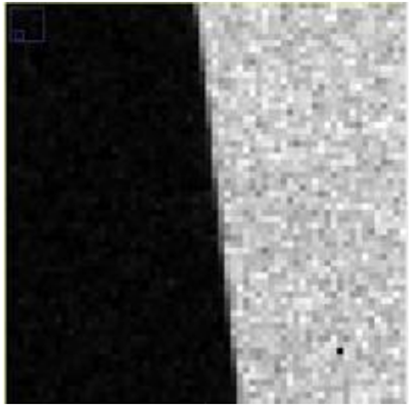
Amsterdam Scientific Instruments

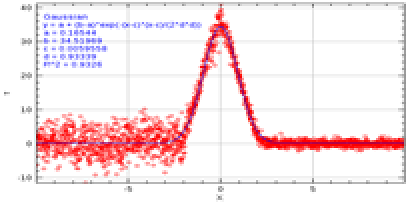
Spatial resolution Si vs GaAs vs CdTe

- TPX3 detectors, X-ray tube 50 kVp, W target, 1 mm plastic cover

<u>Si 300 um</u>

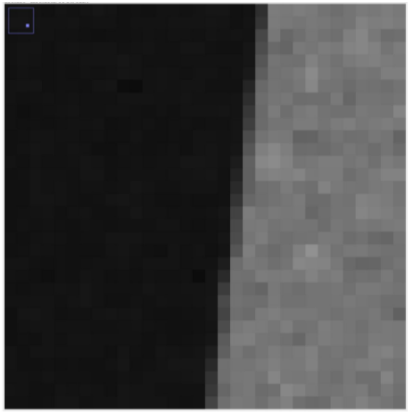
Sigma PSF = 0.9334

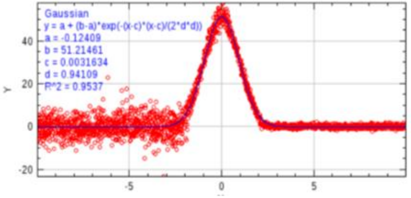




<u>GaAs 500 um</u>

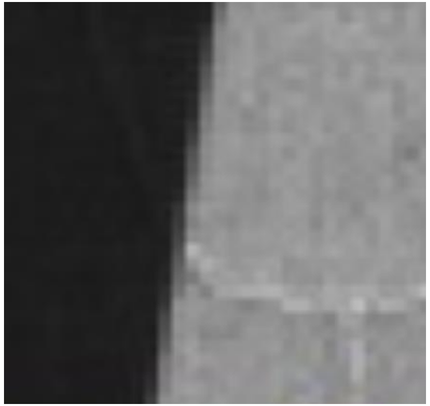
Sigma PSF = 0.9411

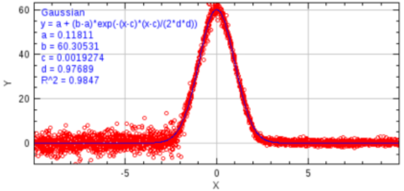




<u>CdTe 1 mm</u>

Sigma PSF = 0.9769





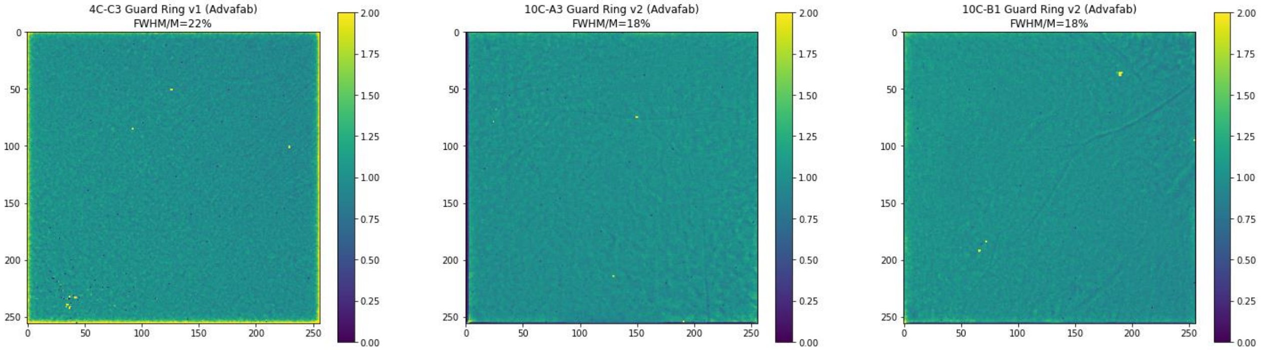
Chromium Compensated of GaAs Sensors Evaluated with MPX3

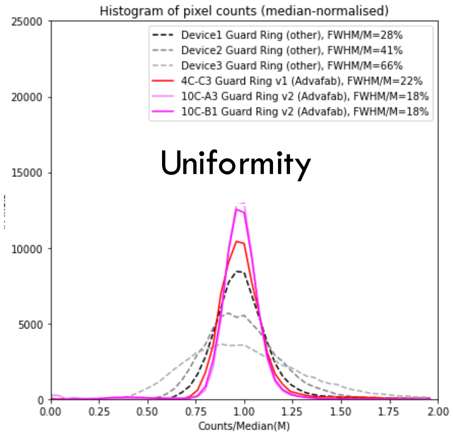
Jörn Lange

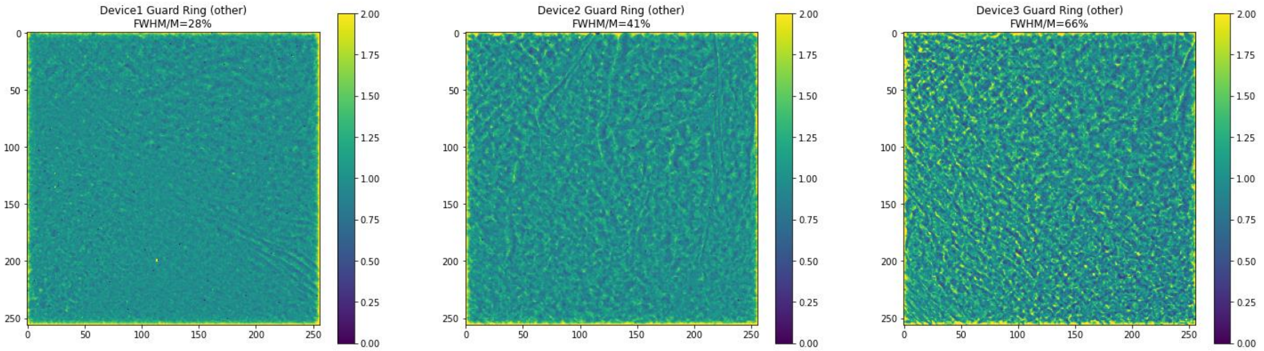
X-Spectrum

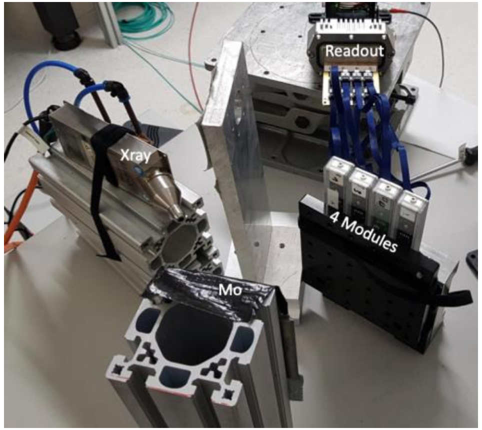
Comparison to commercial material Mo 17.5 keV

Advafab's GaAs





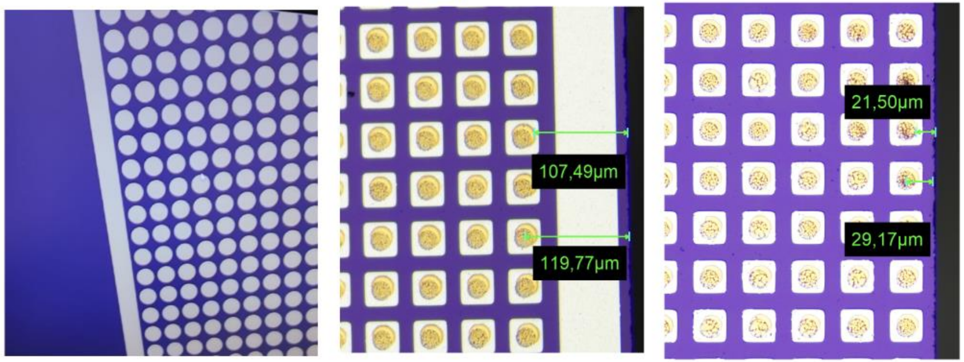


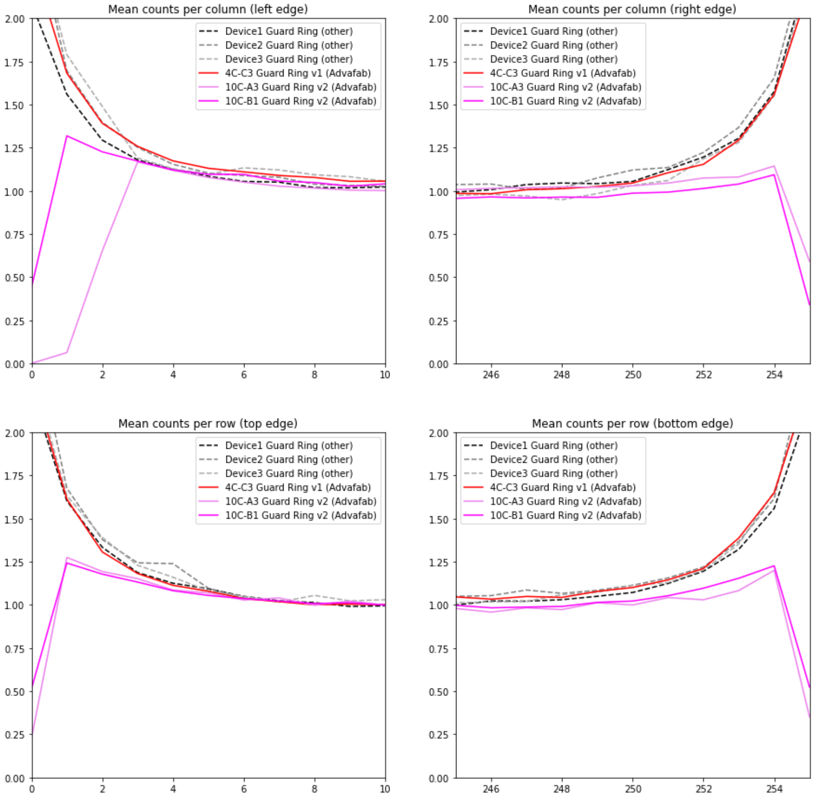


Other's GaAs

Comparison to commercial material Mo 17.5 keV

1st AF GR design (far away cut) | 2nd AF GR design (close cut) | 2nd AF GR design (ultra-slim cut -> GR diced away)





- 1st guard ring design similar
- New 2nd design improved the edge response
- Cutting done close to the guard ring to minimize non active area

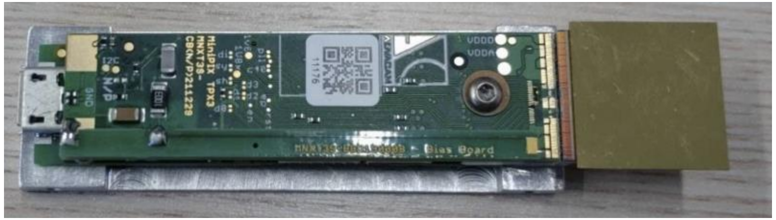
Chromium Compensated of GaAs Sensors Evaluated with TPX2

Jan Jakubek

ADVACAM s.r.o

TPX2 with GaAs sensor 500 µm:

- manufactured by ADVAFAB
- Cr compensated



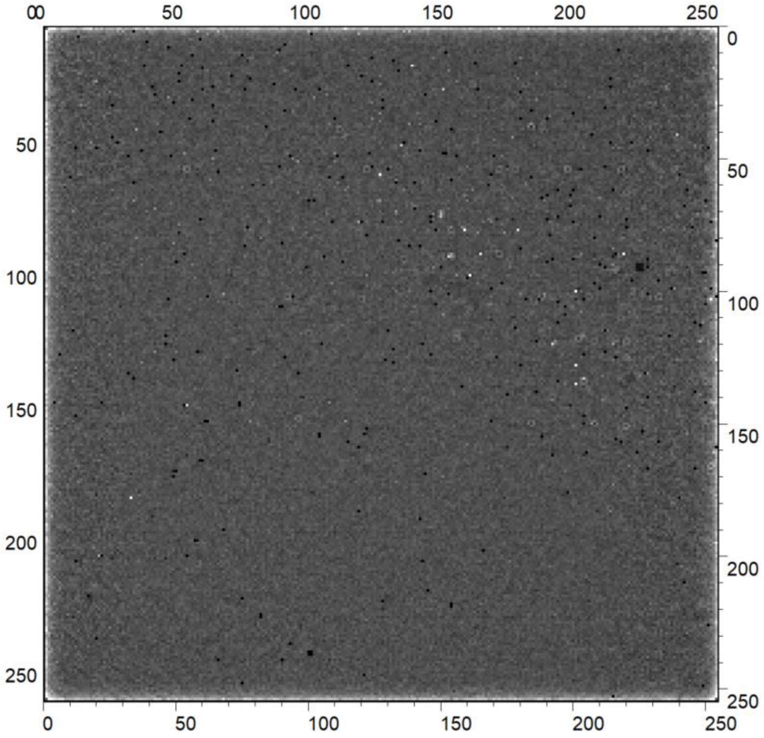
Expectations:

- Other High-Z sensors (CdTe, CZT) exhibit instability
- GaAs is more stable (less polarization)
- If combined with super stable TPX2

$\Rightarrow$ **Super HDR Solution for imaging applications (plastics, biological …)**

Uniformity and spectral properties

Sn XRF (25 keV) flat field image



Result:

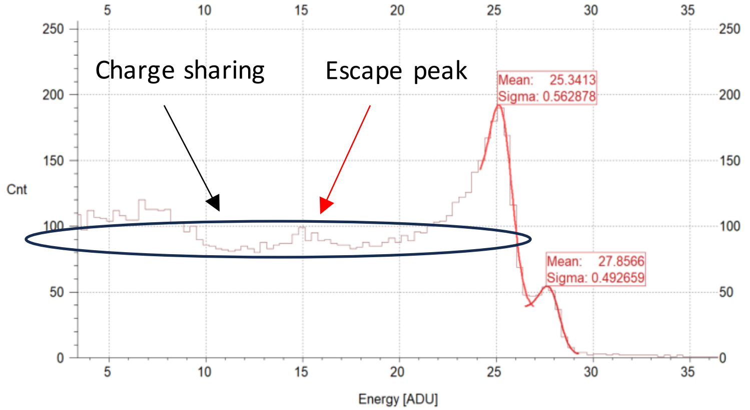
- Threshold 4 keV was used

⇒ **Good uniformity is achievable!**

Uniformity and spectral properties

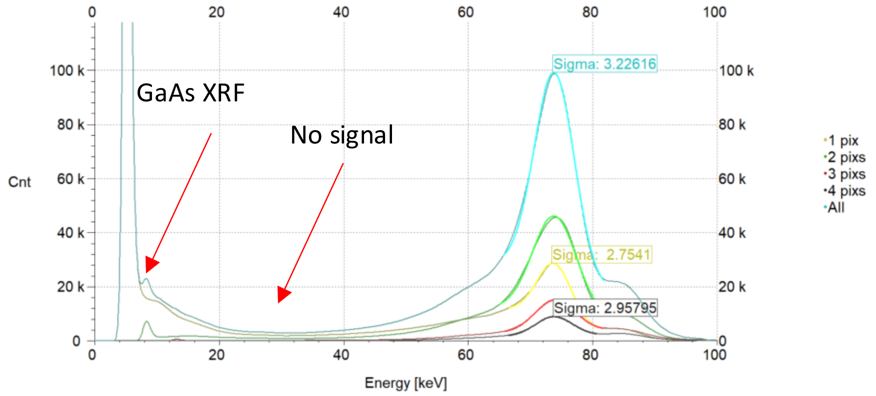
Threshold scan of Sn XRF (25 keV): 5% FWHM energy resolution

Sn XRF spectrum Timepix2+GaAs: Threshold scan



Time over Threshold of Pb XRF (75 keV): 10% FWHM energy resolution

Pb XRF spectra: ToT mode + cluster processing (no charge sharing)



Result:

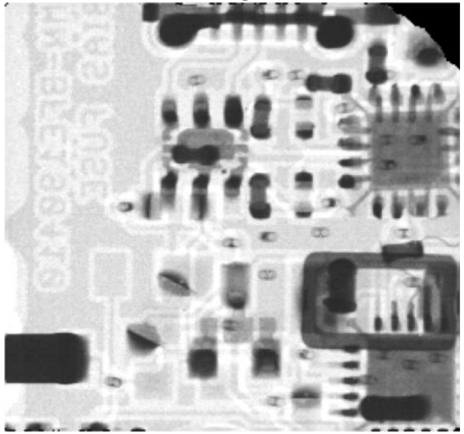
- Threshold 4 keV was used

⇒ **5% TS FWHM @ 25 keV is achievable!**

⇒ **10% ToT FWHM @ 75 keV is achievable!**

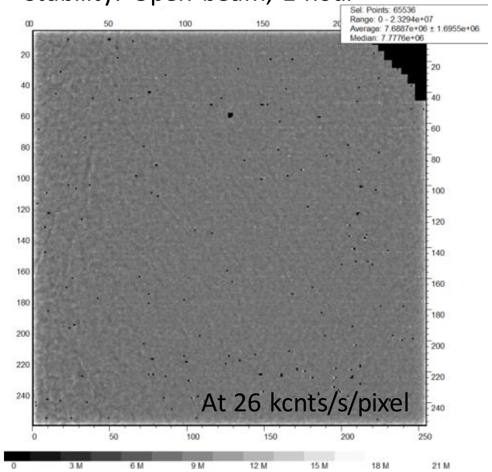
Imaging tests & stability

One of the first images

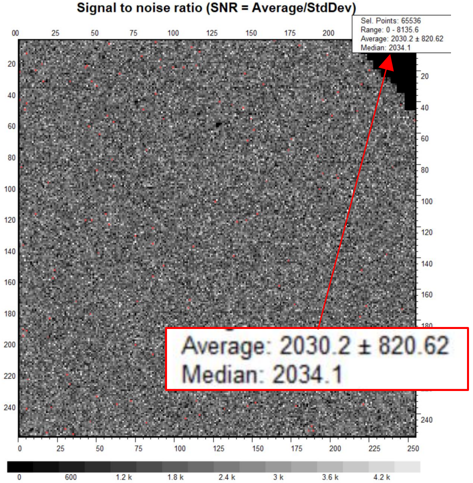


At 7 kcnts/s/pixel

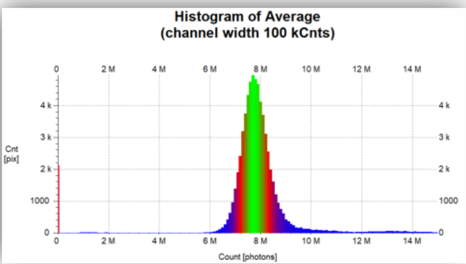
Stability: Open beam, 1 hour

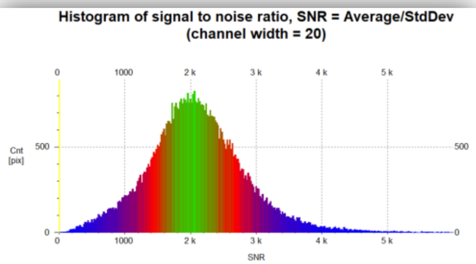


- Exposure 10x30 s => 300 s
- Median: 7.8 Mcnts/pixel



- Wide spread of SNR values
- Median: 2034





Result:

- Promising first results!

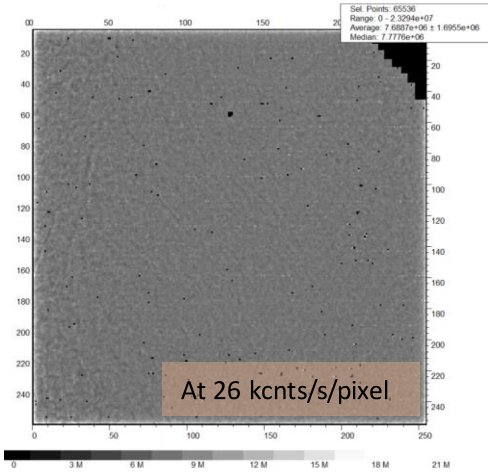
⇒ **SNR of 2000 is achievable!**

⇒ More devices to be tested

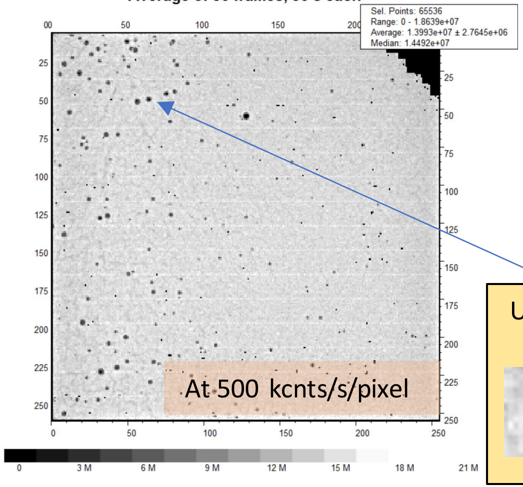
Stability versus intensity: 20x more?

Low intensity: 8.6 Mcnts/s/mm^2

High intensity: 160 Mcnts/s/mm^2 !

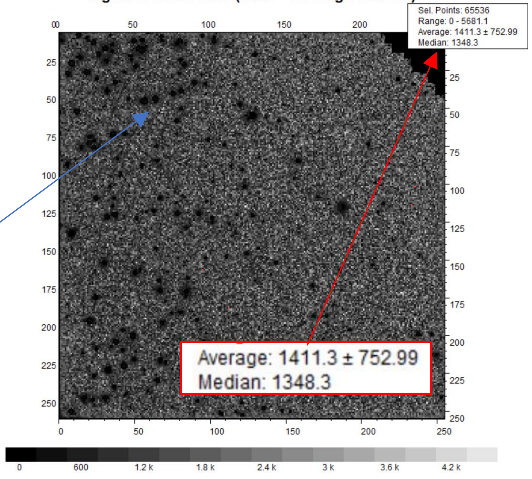


Average of 30 frames, 30 s each

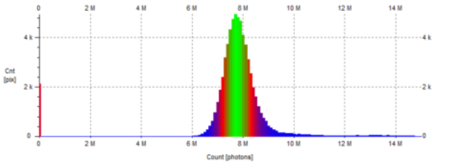


Unstable areas

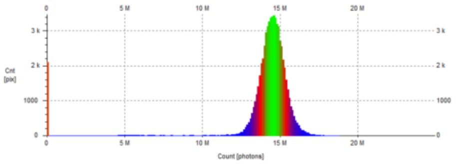
Signal to noise ratio (SNR = Average/StdDev)



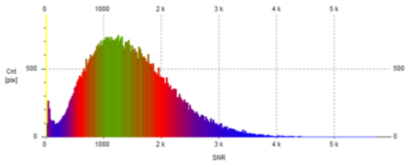
Histogram of Average (channel width 100 kCnts)



Histogram of Average (channel width 100 kCnts)

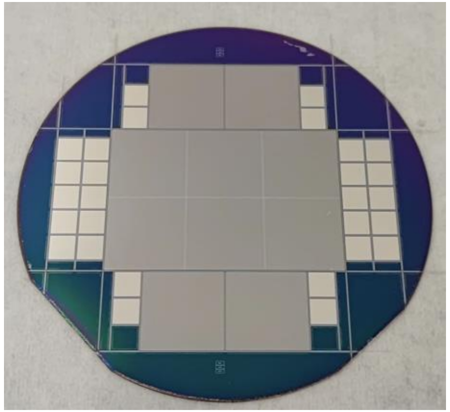


Histogram of signal to noise ratio, SNR = Average/StdDev (channel width = 20)



Contribution for benefit of EUXFEL and further work

- Close R&D relationship with academic and industrial partners that operate in synchrotron market
- Essential to have access and evaluations done in high flux environment using MHz detectors => feedback & limitations
- Process development iterations to meet the demanding requirements
- Production partnership for sensor manufacturing and hybridization



Further work

- Reduce leakage current for charge integrating readout electronics and spectroscopic diodes
- Thicker sensors ~1 mm
- Larger wafer size 3” => 4”